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ASYNCHRONY IN FLUCTUATIONS OF THE MAXIMUM WATER LEVELS OF THE RIVERS IN THE BELARUSIAN POLESIE AND THE BELARUSIAN LAKELAND

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A comparative analysis of the maximum water levels formation of the rivers in the Belarusian Lakeland and the Belarusian Polesie for the period from 1946 to 2015 was carried out. Three periods were studied: 1946…1965 – the period before the mass reclamation, the peri-od of minimal anthropogenic impacts, can be conditionally accepted as a natural water regime; 1966…1987 – the period of mass reclamation; 1988…2015 – the period of modern climatic impacts. The methodological basis of the research was the scientific provisions on the stochastic nature of the variability of the river level regime and the comparative geographical method. It is established that for the rivers of the Belarusian Lakeland there is a steady tendency to decrease the maximum water levels at a rate of minus 31 cm / 10 years in general for the entire period under review, while there is a slight decrease for the rivers of the Belarusian Polesie.

Key words: Belarusian Polesie, Belarusian Lakeland, water level, trend, asynchrony.

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INTRODUCTION

The level regime is the main hydrological characteristic of rivers and it is widely used in solving both theoretical and practical problems. The annual flooding of the floodplain has a beneficial effect on ecosystems, soil moistening occurs, spawning areas are formed, the coastal zone is cleaned etc. Floods are constant in time, so the population of coastal zones has adapted themselves and their economic activities to this phenomenon. The situation is worse when the flood turns into a flood, which leads to economic damage and even human casualties. As for natural river ecosystems, floods should rather be considered as a mechanism contributing to their recovery, since, as a rule, stronger representatives of flora and fauna survive. Modern climatic fluctuations and anthropogenic impacts have undoubtedly had a certain impact on the level regime of rivers. Therefore, by the nature of changes in the level regime, it is possible to assess the influence of various factors to one degree or another.

The purpose of the work is the spatial and temporal assessment of fluctuations in the water levels of the rivers in the Belarusian Polesie and the Belarusian Lakeland on the example of the rivers of the basins of the Western Dvina and Pripyat flowing in various natural and climatic zones.

DATA AND METHODS

The studies used data from observations of the maximum water levels of the rivers of the Western Dvina River basin in the channels (Surazh, Vitebsk, Ulla, Polotsk, Verkhnedvinsk) and the Pripyat River basin in the channels (Pinsk (Lyubansky Bridge), Chernichi, Petrikov, Mozyr, Narovlya). There are a total of 10 hydrological stations with a 70-year observation period from 1946 to 2015, with the exception of the Western Dvina River – Verkhnedvinsk from 1955 to 2015 and the Pripyat River – Pinsk (Lyubansky Bridge) published in (Annual data 1946...2015). Detailed characteristics of the water regime of the studied rivers and hydrographic characteristics of catchments are presented in the works (Western Dvina, 2006; Kalinin M.Yu., 2004, Monitoring, use and management of water resources of the river basin, 2003; Volchek A.A., 2002; Kalinin M.Yu., 2005).

The existing gaps in the series of observations of the maximum water levels were restored by generally accepted methods of hydrological analogy using analogous rivers (Estimated hydrological characteristics, 2010; Volchek A.A., 2021).

The initial time series are divided into three intervals: from 1946 to 1965 – the period before the mass reclamation, the period of minimal anthropogenic impacts, can be conditionally accepted as a natural water regime; from 1966 to 1987 – the period of mass reclamation; from 1988 to 2015 – the period of modern climatic impacts.

The methodological basis of the research is the scientific provisions on the stochastic nature of the variability of the level regime of rivers, which allowed the use of statistical methods of time series analysis, namely correlation and regression analysis, spatial asynchrony functions, spatial correlation functions, etc. A systematic analysis of the accumulated information and a comparative geographical method made it possible to synthesize the most important patterns of spatial and temporal fluctuations in river water levels.

The assessment of the homogeneity of the series of hydrometric observations is carried out on the basis of a genetic analysis of the conditions for the formation of river runoff by identifying the causes that cause the heterogeneity of the initial observation data.

The primary analysis of the homogeneity of hydrological series is recommended to be carried out by graphical methods, which provide for the construction of total (integral) curves of connections from time (Volchek A.A., 2021):

$$\sum_{t=1}^{T} H_{maxt} = f(t), \qquad (1)$$

where $\sum_{t=1}^{T} H_{maxt}$ – the increasing value of the maximum water levels in time; t – the current year; T – the observation period.

Linear trends were used to assess the dynamics of maximum water levels (Statistical methods in nature management, 1999; Loginov V.F., 2004):

$$H_{max}(t) = H_{max}(0) \pm \Delta H_{max} \cdot t, \qquad (2)$$

where $H_{max}(t)$ – the value of the maximum level in the calculated year, $H_{max}(0)$ cm, – the value of the maximum level at the initial time, cm; t – the current year.

The statistical homogeneity of the series of observations relative to the natural level regime of rivers was evaluated by parametric tests, in particular, differences in averages using the Student's criterion, and differences in the nature of fluctuations in the level regime – the Fisher criterion (Statistical methods in nature management, 1999; Loginov V.F., 2004):

$$t = \frac{\overline{H}_{max1} - \overline{H}_{max2}}{\sqrt{n_1 \cdot \sigma_1^2 + n_2 \cdot \sigma_2^2}} \cdot \sqrt{\frac{n_1 \cdot n_2 \cdot (n_1 + n_2 - 2)}{n_1 + n_2}}, \qquad (3)$$

$$F = \frac{\sigma_1^2}{\sigma_2^2}, \qquad (4)$$

where $\overline{H}_{max\,1}, \overline{H}_{max\,2}$ – sample averages of maximum water levels; σ_1^2, σ_2^2 – sample dispersions; n_1 and n_2 – sample volumes.

The obtained value of the Student's t-test and Fisher's F-test were compared with their critical values at a given significance level $\alpha = 5\%$. If $t > t\alpha$, the hypothesis of a statistical difference between the two sample averages is accepted, and if $F > F\alpha$, the hypothesis of a statistical difference in the fluctuations of the series under consideration is accepted.

The asynchronous effect was determined by the method of N.V. Somov. The peculiarity of the method lies in the possibility of unambiguous determination of the quantitative parameters of the asynchrony effect in any zones of the security curve individually and for the entire set of values of the studied quantity. The proposed methodology is based on the determination of the asynchronous effect by the combined curves of the security of the total chronological and equidistant series of values of water levels.

When constructing the security curves of a total equally secured series, the values of water levels are arranged in descending order and summed up, then, depending on the place occupied by each member of such a total decreasing series, it is assigned the corresponding security.

When constructing the security curve of the total chronological series, the modular coefficients of water levels are summed up for the corresponding years in chronological order, then the series is ranked in descending order. The ratio (Loginov V.F., 2006) is used as a quantitative indicator of the degree of asynchrony of water levels:

$$C_{as}(P)=\frac{\sum_{j=1}^{k}\left(c_{ch}(j)\right)}{\sum_{j=1}^{k}\left(c_{mc}(j)\right)}, \quad (5)$$

where $\sum_{j=1}^{k} c_{ch}(j)$ – the sum of chronological ranked modular coefficients; $\sum_{j=1}^{k} c_{mc}(j)$ – the sum of equally secured ranked modular coefficients; k – the number of stations; P – probability.

RESULTS AND DISCUSSION

In the basin of the Western Dvina River, the spring flood develops quite quickly due to the short paths of slope runoff and significant slopes; the maximum lasts for a short time, usually no more than a day, followed by a relatively rapid decline. The Pripyat River flowing in the southern part is not characterized by sharp and high floods.

The rivers in question belong to the type of plains with a predominance of snow nutrition. The distribution of spring runoff in a year is directly dependent on physical and geographical factors, such as relief, the nature of soils, the distribution of precipitation over the territory, the geological structure of the area.

The rivers of the northeastern and southern regions have the greatest difference. The rivers of the north-eastern districts (the Western Dvina River) are located in the most elevated part of the country, flowing in narrow clearly defined valleys, characterized by sharper and significant fluctuations in water levels and flow rates. The southern rivers (Polesie Rivers), located in a flat, heavily swampy area, flowing in wide valleys with extensive floodplains, are characterized by the greatest smoothness of the course of the levels and a low, much stretched flood.

The spring rise of water levels begins a few days before the debacle. The average time of the beginning of the spring rise of levels is observed in the south of the country in late February – early March, in the north – in late March – early April. The highest water levels of the spring flood through-out the country are mainly observed in the third decade of March – the second decade of April.

Table 1 shows the maximum spring flood water levels for the period 1946…2015. In the basin of the Western Dvina River, for all the studied stations, the maximum water levels were observed during the spring flood in the spring of 1956 in the period April 23 …26, which developed downstream. The absolute maximum water level was formed on the Western Dvina River in the alignment of the village of Surazh and reached 146,10 m. In Belarusian Polissya, the formation of maximum water levels is more complicated than in the north of the country.

The spring flood is more stretched; there are several waves of maximum levels. During the research period, the maximum water levels were observed in the spring of 1979 from March 29 to April 10. The stretch of the flood is caused by the small slopes of the catchments, which causes a low rate of melt water reaching.

A shorter flood was observed in 1999 and the maximum water levels were observed from March 21 to March 22. The absolute maximum water level was formed on the Pripyat River in the alignment of Pinsk (Lubansky Bridge) and reached 136,20 m. Figure 1 shows fragments of flooding in 1999 on the Pripyat River. The results obtained are in good agreement with the results of studies on the maximum water consumption given in (Loginov V.F., 2014).

Using integral curves (formula (1), the studied series were checked for uniformity. As the analysis showed, the studied series of observations of the maximum water levels are homogeneous, with the exception of the Pripyat River in the alignment of Chernichi the violation of uniformity is dated to 1986 (Fig. 2). The chronological course of the maximum water levels, the dates of their occurrence, as well as the trend lines for the time intervals under consideration are shown in Figure 3. In general, there is a statistically significant (correlation coefficient r = – 0,36) tendency to decrease the maximum water levels at a rate of – 31 cm / 10 years.

Table 1

Maximum spring flood water levels over a multi-year period

River – station	The highest level in absolute values, m	Date of occurrence of the highest level (number of cases)
Belarusian Lakeland		
Western Dvina River – Surazh	146,10	23.04.1956 (1)
Western Dvina River – Vitebsk	135,32	24.04.1956 (1)
Western Dvina River – Ulla	124,28	24.04.1956 (1)
Western Dvina River – Polotsk	119,32	25.04.1956 (1)
Western Dvina River – Verkhnedvinsk	112,90	25.04.1956 – 26.04.1956 (2)
Belarusian Polesie		
Pripyat River – Pinsk (Lyubansky Bridge)	136,20	29.03.1979 (1)
Pripyat River – Chernichi	128,28	21.03.1999 – 22.03.1999 (2)
Pripyat River – Petrikov	121,88	03.04.1979 – 04.04.1979 (2)
Pripyat River – Mozyr	118,22	08.04.1979 – 10.04.1979 (3)
Pripyat River – Narovlya	117,01	1979

***Fig. 1.** Flood on the Pripyat River in 1999 (Photo by A. Dubrovsky).*

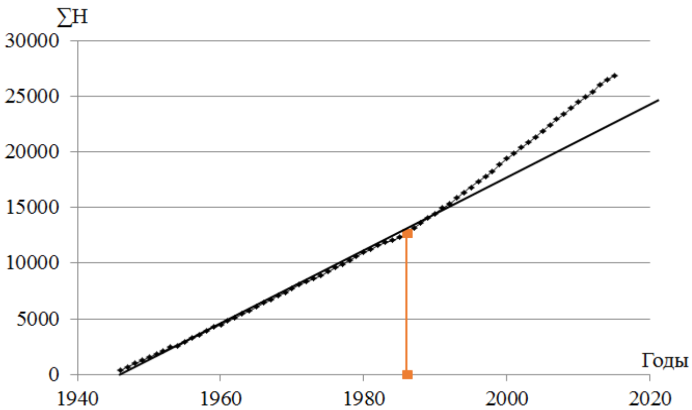
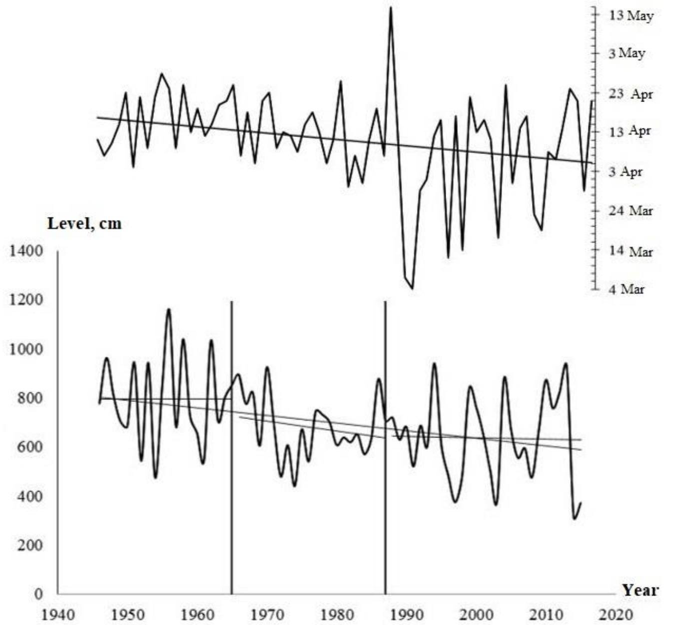


***Fig. 2.** Change in the increasing sum of the maximum water levels of the spring flood of the Pripyat River – Chernichi.*

The period 1946…1965 is characterized by stable maximum water levels, the rate of decline was –0,30 cm / 10 years, which is within the error. It should be noted that the average maximum level is statistically significantly higher than the average maximum level for the entire observation period, at the same time, the nature of fluctuations has not changed.

The period of intensive reclamation transformations is characterized by a decrease in the maximum water levels at a rate of –39 cm/10 years, while there were no statistically significant differences in both the average values and the nature of fluctuations. During the period of modern climatic changes, there is a slight decrease in maximum water levels at a rate of –6 cm / 10 years, without changes in average maximum water levels and the nature of their fluctuations. There is a steady tendency to shift the dates of the onset of maximum water levels to earlier dates by an average of 10 days. A similar pattern is observed for other rivers of the Belarusian Lakeland (Table 2).



—— – trend lines; vertical lines: the first line is the year of the beginning of large–scale reclamation, the second line is the year of the beginning of modern warming

Fig. 3. *Long-term fluctuations of maximum water levels and the dates of their occurrence of the Western Dvina River – Vitebsk.*

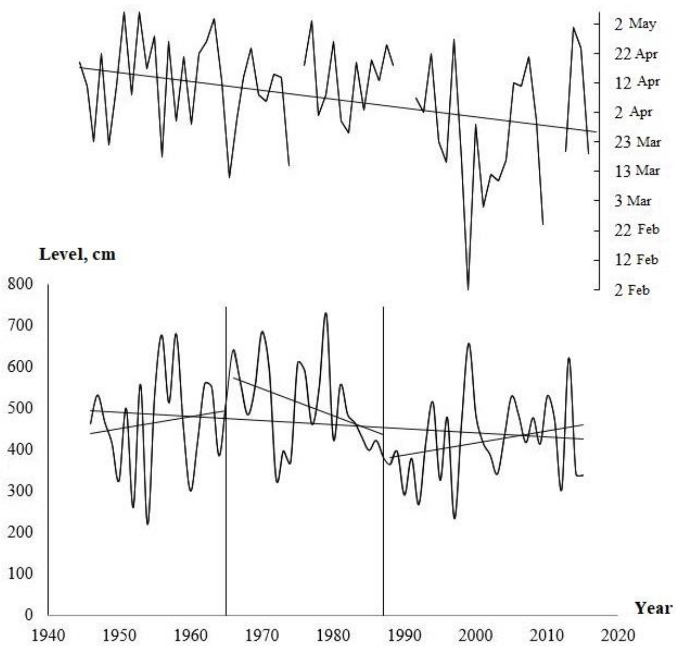
The chronological course of the maximum water levels, the dates of their occurrence, as well as the trend lines for the time intervals under consideration are shown in Figure 4. In general, the dynamics of maximum levels on the rivers of the Belarusian Polesie is more complex than on the rivers of the Belarusian Lakeland. Here there is both an increase in maximum water levels and a decrease. During the period under review along the Pripyat River in the alignment of Mozyr there is a slight decrease in maximum water levels at a rate of -10 cm / 10 years, this value is not statistically significant and it can be assumed that during this period there is a steady dynamics in fluctuations of maximum water levels. In the period before the mass reclamation of the Belarusian Polesie, there was a slight increase in the maximum water levels at a rate of 29 cm /10 years. The period of large-scale reclamation of the Belarusian Polesie was characterized by a massive discharge of centuries-old groundwater reserves, which led to the liberation of the pore space that accumulated melt water. As a result, there was a drop in maximum water levels at a rate of -66 cm/10 years.

As the functions of reclamation systems decreased, in particular, the capacity of the regulating and conducting network decreased, in particular, the capacity of the regulating and conducting network decreased, natural ecosystems began to recover, which led to an increase in maximum water levels at a rate of 29 cm/10 years. A more detailed picture of the other channels is presented in Table 2. There is a steady shift of the dates of the onset of maximum water levels to earlier dates by an average of 15 days.

Table 2

Statistical parameters of the maximum water levels of the rivers of the basins of the Western Dvina River and the Pripyat River

Averaging interval	Water level, H_{abs}, m			Coefficient of variation	Gradient of water level change, Δh, cm/10 years / r	Criteria	
	H_{cp}	H_{max}	H_{min}			Student t_{st} / t_{cr}	Fisher F/F_{cr}
Belarusian Lakeland							
Western Dvina River – Surazh							
1946-2015	142.80	146.10	139.62	0.20	-24.6 / **-0.36**	–	–
1946-1965	143.60	146.10	141.41	0.17	-24.7 / -0.11	**-2.31** / 2.04	1.03 / 1.97
1966-1987	142.65	144.50	140.78	0.15	-20.8 / -0.13	0.53 / 2.01	1.78 / 1.90
1988-2015	142.34	144.72	139.62	0.22	-7.6 / -0.04	1.45 / 2.01	**0.94** / 0.61
Western Dvina River – Vitebsk							
1946-2015	130.66	135.32	126.85	0.25	-30.8 / **-0.36**	–	–
1946-1965	131.66	135.32	128.46	0.22	-0.3 / 0.00	**-2.20** / 2.04	**0.93** / 0.58
1966-1987	130.51	132.96	128.12	0.18	-39.1 / -0.20	0.46 / 2.01	**1.91** / 1.90
1988-2015	130.07	133.13	126.85	0.27	-5.7 / -0.03	1.50 / 2.01	**0.98** / 0.61
Western Dvina River – Ulla							
1946-2015	119.18	124.28	114.98	0.25	-30.7 / **-0.33**	–	–
1946-1965	120.31	124.28	117.22	0.23	-3.4 / -0.01	**-2.17** / 2.05	**0.85** / 0.58
1966-1987	118.84	121.30	116.59	0.18	-34.8 / -0.17	0.96 / 2.01	**2.09** / 1.90
1988-2015	118.66	121.88	114.98	0.27	-0.8 / 0.00	1.24 / 2.01	1.01 / 1.77
Western Dvina River – Polotsk							
1946-2015	114.67	119.32	110.67	0.22	-28.5 / **-0.31**	–	–
1946-1965	115.68	119.32	112.52	0.21	-2.3 / -0.01	-1.98 / 2.05	**0.82** / 0.58
1966-1987	114.47	116.63	112.25	0.17	0.6 / 0.00	0.54 / 2.01	1.75 / 1.90
1988-2015	114.11	117.14	110.67	0.22	2.0 / 0.01	1.38 / 2.01	1.07 / 1.77
Western Dvina River – Verkhnedvinsk							
1955-2015	107.29	112.90	103.08	0.26	-33.7 / **-0.29**	–	–
1955-1965	108.79	112.90	105.22	0.24	-151 / -0.21	-1.94 / 2.16	**0.73** / 0.50
1966-1987	107.19	109.59	104.15	0.22	12.2 / 0.05	0.24 / 2.02	1.42 / 1.92
1988-2015	106.79	110.36	103.08	0.26	-3.2 / -0.01	1.12 / 2.00	1.12 / 1.79
Belarusian Polesie							
Pripyat River – Pinsk (Lyubansky Bridge)							
1979-2015	135.27	136.20	134.09	0.24	-3.0 / -0.05	–	–
1979-1987	135.38	136.20	134.50	0.20	-78 / -0.45	-0.61 / 2.16	1.16 / 3.06
1988-2015	135.23	136.20	134.09	0.25	7.0 / 0.10	0.27 / 2.00	**0.95** / 0.56
Pripyat River – Chernichi							
1946-2015	125.75	128.28	123.35	0.27	40.0 / **0.77**	–	–
1946-1965	124.92	125.71	123.35	0.17	9.0 / 0.10	**4.84** / 2.00	**4.01** / 1.97
1966-1987	125.15	126.84	123.86	0.18	-1. / -0.01	**3.39** / 2.00	**3.21** / 1.90
1988-2015	126.81	128.28	125.54	0.12	17.0 / 0.23	**-6.25** / 1.99	1.05 / 1.56
Pripyat River – Petrikov							
1946-2015	120.25	121.88	117.85	0.10	-3.0 / -0.07	–	–
1946-1965	120.18	121.37	117.85	0.11	19.0 / 0.12	0.33 / 2.05	**0.79** / 0.58
1966-1987	120.52	121.88	118.43	0.09	-44.0 / -0.38	-1.43 / 2.03	1.15 / 1.90
1988-2015	120.10	121.56	118.26	0.10	12.0 / 0.13	0.92 / 2.01	1.17 / 1.77
Pripyat River – Mozyr							
1946-2015	115.53	118.22	113.12	0.25	-10.0 / -0.18	–	–
1946-1965	115.59	117.73	113.12	0.26	29.0 / 0.14	-0.20 / 2.05	**0.85** / 0.57
1966-1987	115.98	118.22	114.20	0.21	-66.0 / -0.39	-1.66 / 2.03	1.10 / 1.90
1988-2015	115.14	117.50	113.26	0.23	29.0 / 0.24	1.69 / 2.00	1.29 / 1.77
Pripyat River – Narovlya							
1946-2015	114.13	117.01	111.24	0.28	-1.0 / -0.02	–	–
1946-1965	113.95	116.49	111.24	0.34	72.0 / 0.30	0.52 / 2.05	**0.72** / 0.57
1966-1987	114.61	117.01	112.70	0.25	-70.0 / -0.39	-1.68 / 2.03	1.02 / 1.90
1988-2015	113.88	115.86	112.20	0.23	40.0 / 0.36	1.12 / 2.00	1.63 / 1.77



—— – trend lines; vertical lines: the first line is the year of the beginning of large–scale reclamation, the second line is the year of the beginning of modern warming

***Fig. 4.** Long-term fluctuations of maximum water levels and the dates of their occurrence of the Pripyat River – Mozyr.*

The dependence of the coefficients of asynchrony between the maximum water levels of the Pripyat River in the alignment of the city of Mozyr and the Western Dvina River in the alignment of the city of Vitebsk. So for a very high-water year, the asynchronous coefficient of Cas (P=5%) = 0,97, and for a very low-water year Cas (P=95%) = 1,05. In the course of the research, a relationship was obtained between the dates of the maximum water levels of the Pripyat River in the alignment of the city of Mozyr and the Western Dvina River in the alignment of the city of Vitebsk:

$$t_{West\ Dv.}=0.3\cdot t_{Pr}+77, \quad (6)$$

$$r=0{,}43,$$

where tWest Dv.– the date of the onset of the maximum water level on the Western Dvina River in the alignment of Vitebsk, counting from 1.01; tPr – the time shift of the onset of the maximum water levels of the spring flood on the Pripyat River.

CONCLUSION

Thus, on the rivers of the Belarusian Lakeland there is a general steady trend towards a decrease in maximum water levels at a rate of -31 cm/10 years and a shift in the dates of their onset to an earlier period. During the period under review, this shift was about 10 days. A more complex picture is observed on the rivers of the Belarusian Polesie. Here there is both an increase in maximum water levels and a decline in individual periods under study. So, in general, there is a slight drop in the maxi-mum water levels in the regions at a rate of about -10 cm/10 years. In the period before the mass reclamation of the Belarusian Polesie, there was a slight increase in the maximum water levels at a rate of 29 cm /10 years. Large-scale land reclamation caused a decrease in maximum water levels. During the period of modern climate warming, there is a certain increase in the maximum water levels on the rivers of the Belarusian Polesie. During the period under review, this shift was about 15 days. Synchronicity in the fluctuations of the maximum water levels of the Western Dvina River in the alignment of Vitebsk and the Pripyat River in the alignment of Mozyr is estimated by a correlation coefficient of 0,58, and the coefficient of asynchrony for a very high-water year Cas (P=5%)=0,97, and for a very low-water year Cas (P=95%)=1,05.

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АСИНХРОННОСТЬ КОЛЕБАНИЙ МАКСИМАЛЬНОГО УРОВНЯ ВОДЫ РЕК БЕЛОРУССКОГО ПОЛЕСЬЯ И БЕЛОРУССКОГО ПООЗЕРЬЯ

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Проведен сравнительный анализ формирования максимальных уровней воды рек Белорусского Поозерья и Белорусского Полесья за период с 1946 по 2015 гг. Были изучены три периода: 1946...1965 гг. – период до начала массовых мелиораций, т.е. период минимального антропогенного воздействия, можно условно принять за естественный водный режим, 1966...1987 гг. – период массовых мелиораций, 1988...2015 гг. – период современных климатических воздействий. Методологическую основу исследования составили научные положения о стохастическом характере изменчивости уровенного режима рек и сравнительно-географический метод. Установлено, что для рек Белорусского Поозерья за весь рассматриваемый период наблюдается устойчивая тенденция снижения максимальных уровней воды со скоростью -31 см/10 лет, в то время как для рек Белорусского Полесья наблюдается незначительное снижение.

Ключевые слова: Белорусское Полесье, Белорусское Поозерье, уровень воды, тенденция, асинхронность.

БЕЛОРУС ПОЛЕСИЯСЫ ЖӘНЕ БЕЛОРУС ПООЗЕРИЯСЫ ӨЗЕНДЕРІНІҢ ШЕКТІ СУ ДЕҢГЕЙІНІҢ ӨЗГЕРІСТЕРІ

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Белорус Полесиясы және Белорус Поозериясы өзендерінің 1946...2015 жж. кезеңі бойынша максималды су деңгейлерінің қалыптасуының салыстырмалы талдауы жүргізілді. Сол мерзім ішінде үш кезең зерттелді: 1946...1965 жж. – жаппай мелиорациялау басталғанға дейінгі кезең, яғни ең аз антропогендік әсер ету кезеңі, шартты табиғи су режимі ретінде алуға болады, 1966...1987 жж. – жаппай мелиорациялау кезеңі, 1988...2015 жж. - қазіргі климаттық әсерлер кезеңі. Өзендердің деңгейлік режимі өзгерісінің стохастикалық сипаты туралы ғылыми ережелер және салыстырмалы географиялық әдісі зерттеудің негізгін құрады. Белгілі болғандай, Беларусь Поозериясы өзендері үшін барлық қарастырылып отырған кезеңде судың максималды деңгейінің 10 жылда 31 см жылдамдықпен тұрақты төмендеу тенденциясы байқалады, ал Беларусь Полесиясы өзендері үшін су деңгейінің аздап төмендеуі байқалады.

Түйін сөздер: Беларусь Полесиясы, Беларусь Поозериясы, су деңгейі, тенденция, асинхрондылық.